



# UCSD Seminar



## ***UAV Research, Operations, and Flight Test at the NASA Dryden Flight Research Center***

**Gary B. Cosentino**  
**NASA Dryden Flight Research Center**





# *Outline*

- **UAV's for Science and Experimental Applications**
  - Perseus B
  - Altus II
  - Altair
  - Ikhana
  - Global Hawk
- **UAV's for Flight Research and Demonstration Purposes**
  - X-36
  - X-45A
  - X-48B
- **Small UAV's for Customers (sUAS Operations)**
- **Questions & Discussion**



# Perseus B



- **Aurora Flight Sciences Perseus B HALE Aircraft:**
  - Piston-powered, turbocharged with intercooling
  - Designed and built as a remotely piloted aircraft for high altitude science missions
  - Flight tested at Dryden in late 1990's



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/gallery/photo/index.html>  
NASA Photo: EC98-44529-2 Date: April 27, 1998 Photo by: Tony Landis

Perseus B Taxi Tests in Preparation for a New Series of Flight Tests



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/gallery/photo/index.html>  
NASA Photo: EC98-44585-3 Date: June 5, 1998 Photo by: Jim Ross

Aurora Flight Sciences' Perseus B Remotely Piloted Aircraft in Flight





# Altus II



- **General Atomic Altus II HALE Aircraft:**

- Piston-powered, turbocharged with intercooling
- Designed and built as a remotely piloted aircraft for high altitude science missions
- Flight tested at Dryden in the late 1990's
- Successfully conducted several science missions and is still in flyable storage



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/gallery/photo/index.html>  
NASA Photo: EC98-44684-1 Date: 29 Jun 1998 Photo by: General Atomics

Altus II aircraft flying over southern California desert



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/gallery/photo/index.html>  
NASA Photo: EC99-45006-2 Date: May 1999 Photo by: Sandia Labs/Dick Jones  
Altus II high altitude science aircraft descending toward U.S. Navy's Pacific Missile Range Facility on Kauai, Hawaii





# Altair



- **General Atomics Altair HALE Aircraft:**

- High-altitude long endurance variant of early version of Predator B aircraft
- Designed and built as a remotely piloted aircraft for high altitude science missions
- Turbine powered (turboshaft engine)
- Successfully conducted several science missions and is still in flyable storage



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED03-0078-4 Date: March 7, 2003 Photo By: GA-ASI/Alan Waide

Long wings, a V-tail with a ventral fin and a rear-mounted engine distinguish the Altair, an unmanned aerial vehicle built for NASA by General Atomics Aeronautical Systems, Inc.



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED06-0208-1 Date: October 25, 2006 Photo By: General Atomics Aeronautical Systems, Inc.

A high-tech infrared imaging sensor in its underbelly pod, the Altair UAS flew repeated passes over the Esperanza fire to aid firefighting efforts.



# Ikhana



- **General Atomics NASA Predator B “Ikhana” Aircraft:**
  - Based very closely on production Predator B aircraft
  - Designed and built as a remotely piloted aircraft for science missions and payload experiments
  - Turboshaft powered
  - Fully operational Dryden-owned aircraft



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED08-0151-07 Date: July 2, 2008 Photo By: Tony Landis

Ground crewmen prepare NASA's Ikhana remotely piloted research aircraft for another flight. Ikhana's infrared imaging sensor pod is visible under the left wing.



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED07-0038-028 Date: March 5, 2007 Photo By: Tony Landis

Narrow wings, a Y-tail and rear engine layout distinguish NASA's Ikhana aircraft, a civil variant of General Atomics' Predator B unmanned aircraft system.



# Global Hawk



- **Northrop-Grumman NASA Global Hawk Aircraft:**
  - ACDT Global Hawks AV-1 and AV-6 aircraft turned over to NASA from Air Force
  - Designed and built as fully autonomous aircraft for science missions and payload experiments
  - Turbofan powered
  - Soon-to-be fully operational Dryden-owned aircraft



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED07-0244-78 Date: December 3, 2007 Photo By: Tony Landis

In its new white-and-blue NASA livery, an early development model of the Global Hawk unmanned aircraft rests on the ramp at the Dryden Flight Research Center.



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
NASA Photo: ED08-0309-24 Date: December 11, 2008 Photo By: Tony Landis

This and a companion Global Hawk unmanned aircraft are used by NASA for Earth science missions and by Northrop Grumman for developmental testing.





# X-36



- **X-36 Tailless Fighter Agility Research Aircraft:**
  - 28% scale of a notional tailless fighter aircraft
  - Designed and built as a remotely piloted aircraft to demonstrate controllability and agility
  - Used “CFD-to-Flight” methodology almost exactly as described in paper



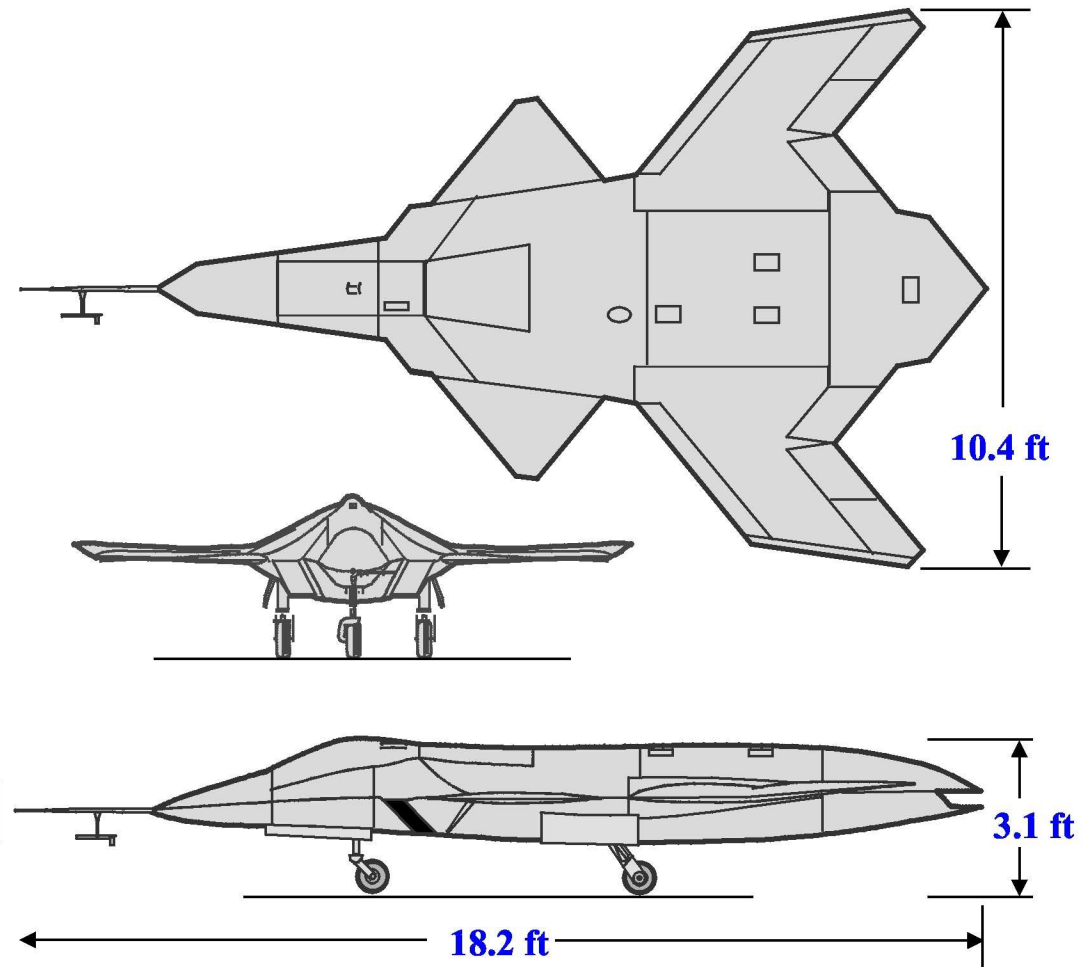


# X-36 Overview



**Weights**

**Performance**



## Materials

**Skin - Carbon Epoxy and Aluminum**

**Assembly - Mechanical Attachment**

**Bones - Machined Aluminum**

**Nozzle - Cast**

**Chem Mill Titanium**



# *X-36 in Flight*







# ***X-36 Flight Summary***



## **Flight Test Highlights**

- 31 Flights May 17 - November 12, 1997
- 4.8 G's maximum
- 52 to 206 KEAS
- 3 Pilots from Boeing and NASA
- 15 hrs 38 mins Flight Time
- 3<sup>deg</sup> to 40<sup>deg</sup> Angle of Attack
- 20,200 ft. Max Altitude
- 8 Flights Accomplished in 9 Work Days



# X-45A



- **Unmanned Combat Air Vehicle (UCAV) Demonstrator:**
  - Full scale of a notional tailless unmanned combat system aircraft
  - Designed and built as an autonomous aircraft to demonstrate concept
  - Used “CFD-to-Flight” methodology again with great success

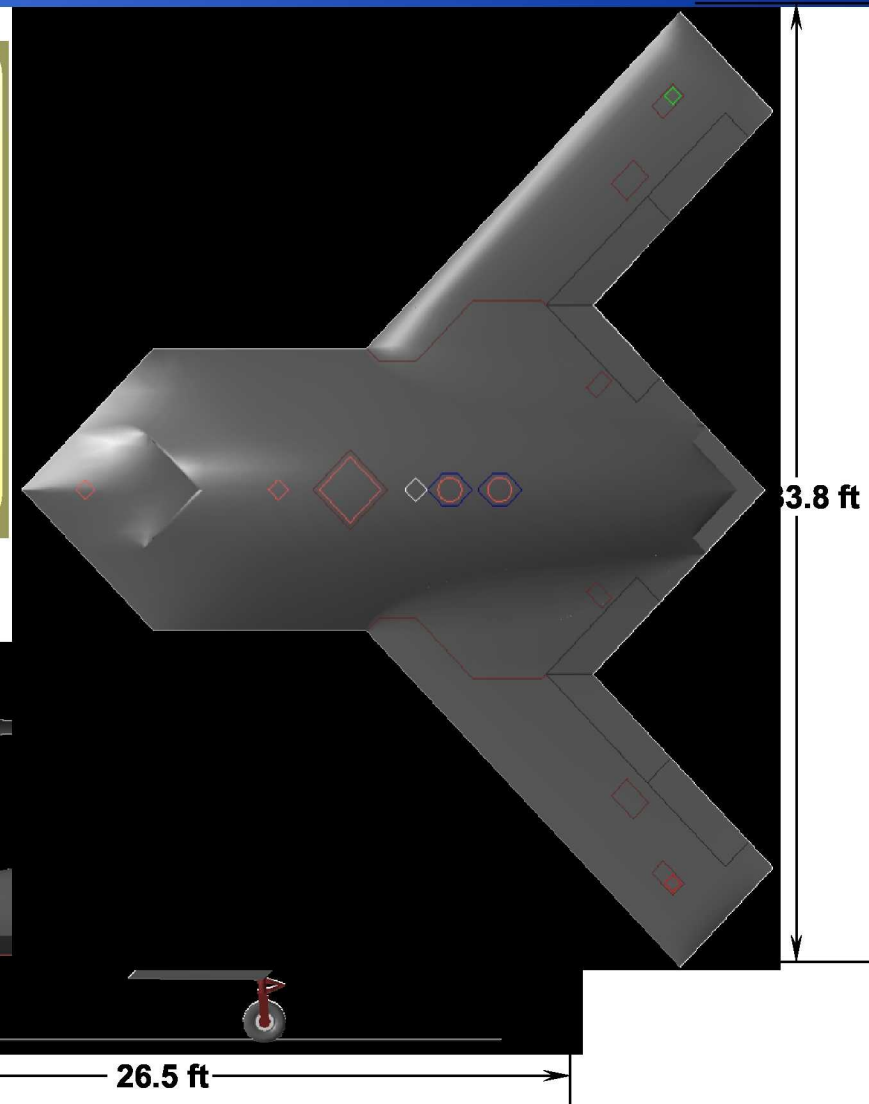
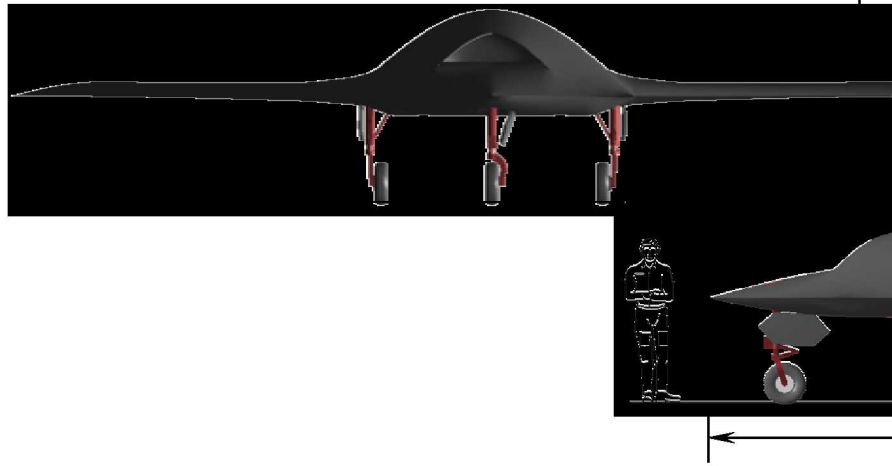




## X-45A Overview



**Boeing X-45A**  
**Empty Weight: 8,000 lb**  
**Fuel Volume: 2,690 lb**  
**Payload Capability: 1,500 lb**  
**Operating Altitude: 35,000 ft**  
**Cruise Mach: 0.75**  
**Engine: Honeywell F124-GA-100**







# *X-45A in Flight*





# ***X-45A Flight Summary***



## **Flight Test Highlights**

- 64 Flights May 22, 2002 - August 10, 2005
- Many, many UAV firsts achieved
- 12 flights dual-vehicle
- Max speed Mach 0.75
- X-45A-1 40 flights total
- X-45A-2 24 flights total
- 63.4 hours flight time total
- 35,000 ft. Max Altitude





# X-48B



- **Blended Wing-Body (BWB) Demonstrator Aircraft:**

- 8.5% scale of a notional future “hybrid” wing-body cargo/tanker/transport aircraft
- Designed and built as a remotely piloted research aircraft for controllability studies
- Designed originally 20 years ago by McDonnell-Douglas Long Beach as future transport
- Unusual shape promises large improvements in fuel efficiency, load capacity
- Aerodynamically efficient way of moving a large volume through the air



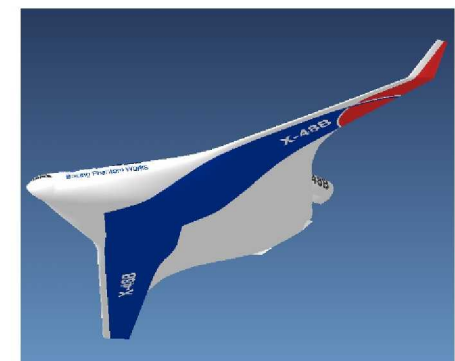
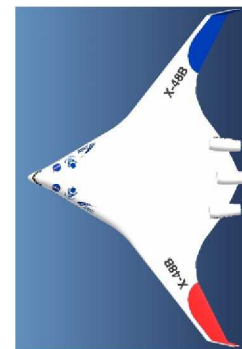




# ***X-48B Flight Research Program***



- **Flight research provides:**
  - Flight Control System risk reduction
  - Required to ensure BWB configuration is as safe as a conventional airplane
- **Investigate:**
  - Stall Characteristics
  - Departure Onset Boundaries
  - Asymmetric Thrust Control
  - Flight Control Algorithms
  - Envelope Protection Schemes
  - Dynamic Ground Effects
  - Control Surface Hinge Moments





## ***Major Program Accomplishments***

- 56 successful flights including 2 flights in 1 day several times
- Completion of envelope expansion phases in both slats extended and slats retracted configurations
- Aircraft capable of operating from hard surface and lakebed runways at Dryden
- Both Boeing and NASA pilots trained to fly aircraft and first NASA pilot mission flown on 8/13/08
- High quality data for various maneuvers recorded and archived for future use
- Preliminary data analysis ongoing with quick look data report for first 20 flights available early 2009
- Ten high AOA flights (near stall) performed in slats extended configuration and stable AOA limits found
- Multiple versions of software upgrades performed resulting in stable test platform
- Takeoffs, landings, low approaches, and go-arounds are routine operations



# ***X-48B BWB Low Speed Vehicle***

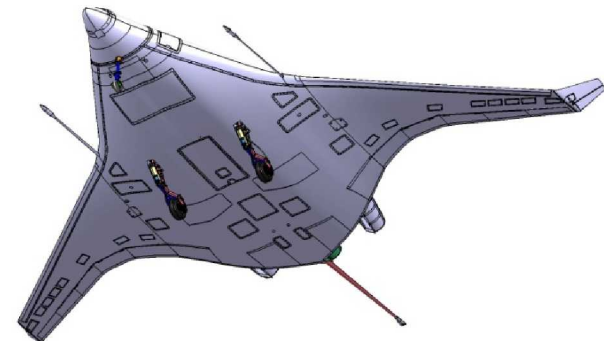
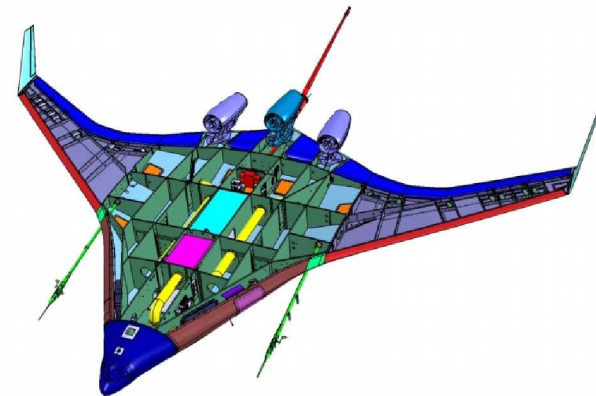


- **Two X-48B Aircraft and Ground Control Station (GCS)**

- Research Partnership of Boeing, NASA, and AFRL
- Design and fabrication contracted to Cranfield Aerospace

- **Air Vehicle Highlights:**

- Dynamically Scaled
- Uninhabited Air Vehicle
  - Flown by Pilot from Ground Station
- Powered by 3 Small Turbojets
  - ~52 lbs. of Thrust Each
- Conventional takeoff and landing
  - Non-retractable Tricycle Gear
  - Slats are Fixed for either Extended or Retracted Configuration
- Recovery System
  - Drogue, Parachute, and Air Bags







# X-48B Vehicle

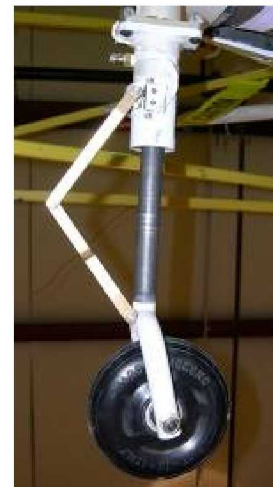


- **Design Approach**

- Use low cost (COTS) equipment where possible
  - Engines - JetCat P-200
  - Landing Gear - mountain bike shocks & brakes
- Use normal industry practice for electronic equipment
- Use aircraft spec equipment where necessary
  - Radios, IMU, Actuators, Flight Termination System (FTS) parts
- Save weight to meet dynamic scaling requirements



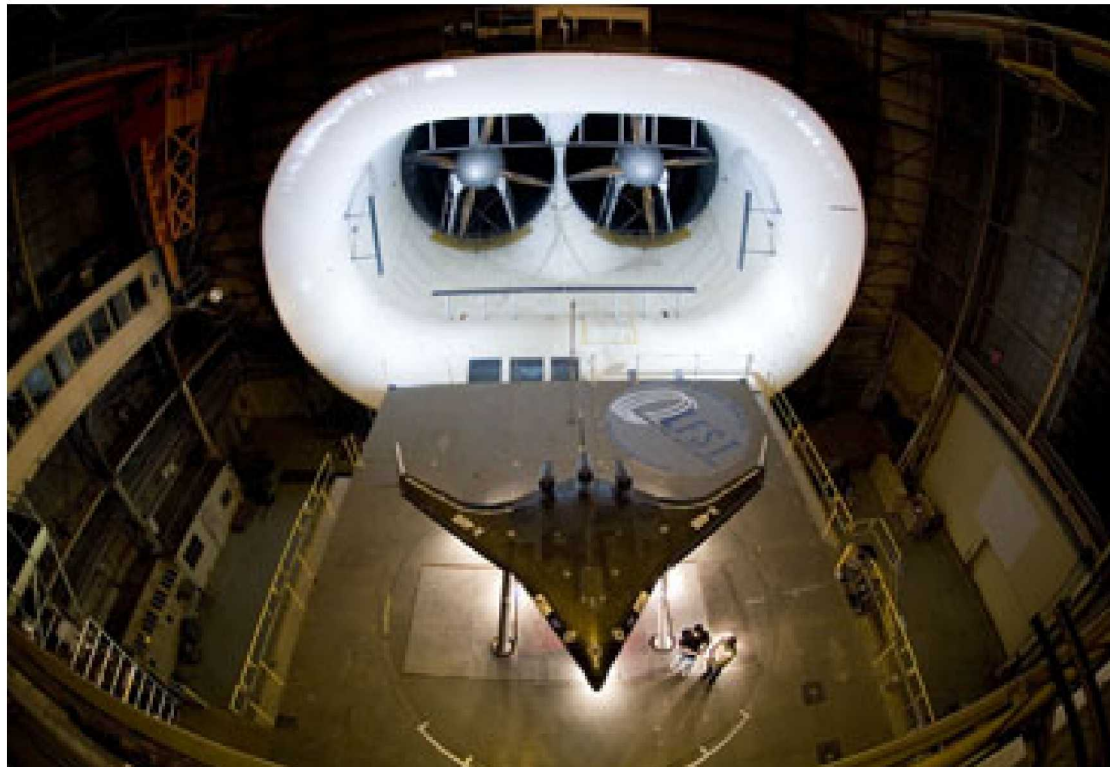
***JetCat P200 Engines***



***Nose & Main  
Landing Gear***



## *X-48B 30x60 Wind Tunnel Test*

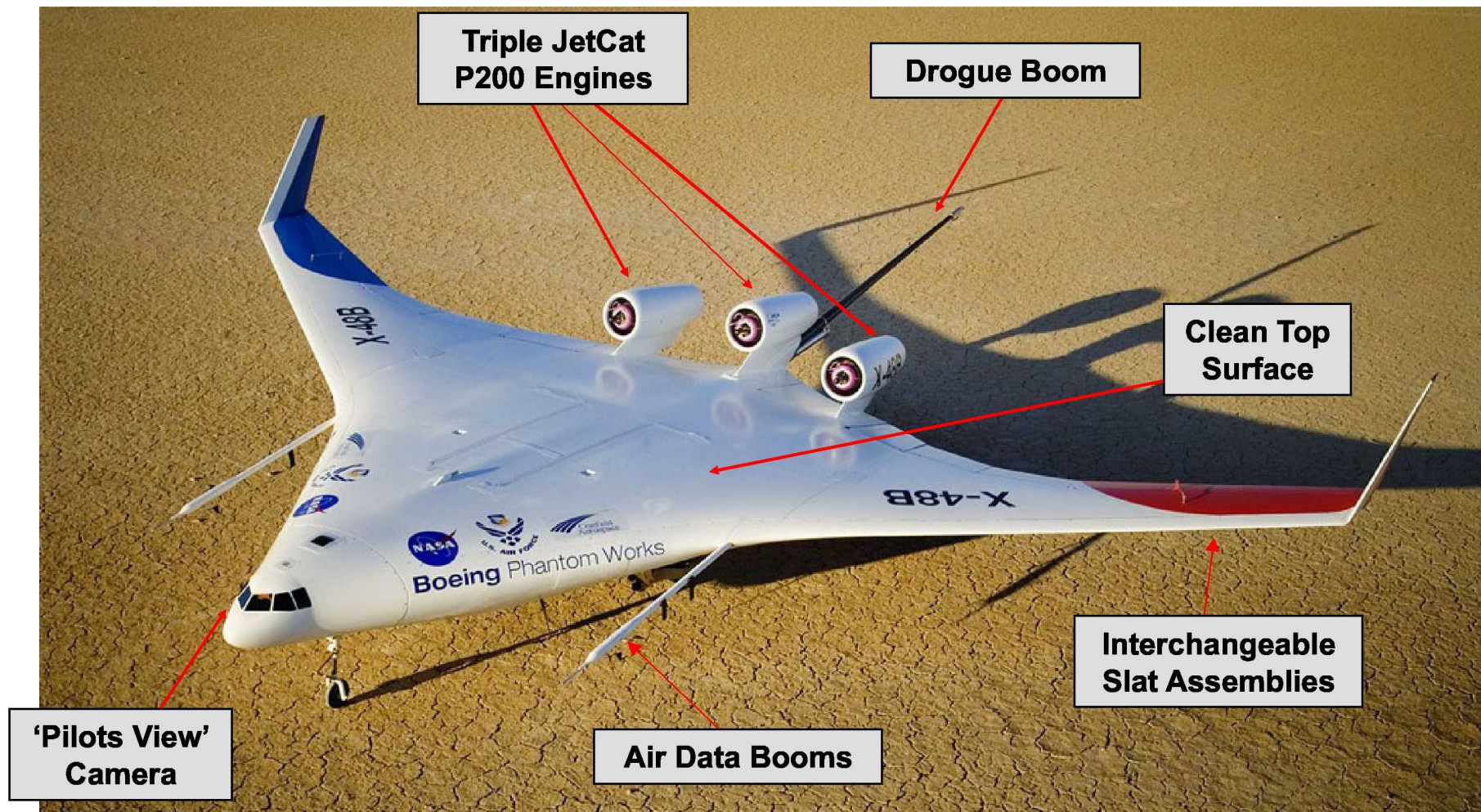


- *NASA / AFRL contributed test time in ODU Langley Full-Scale Tunnel*
- *Wind tunnel test completed April / May 2006*
- *250 hours of testing with flight control hardware active*
- *Data used by Boeing for X-48B simulation and flight control software*





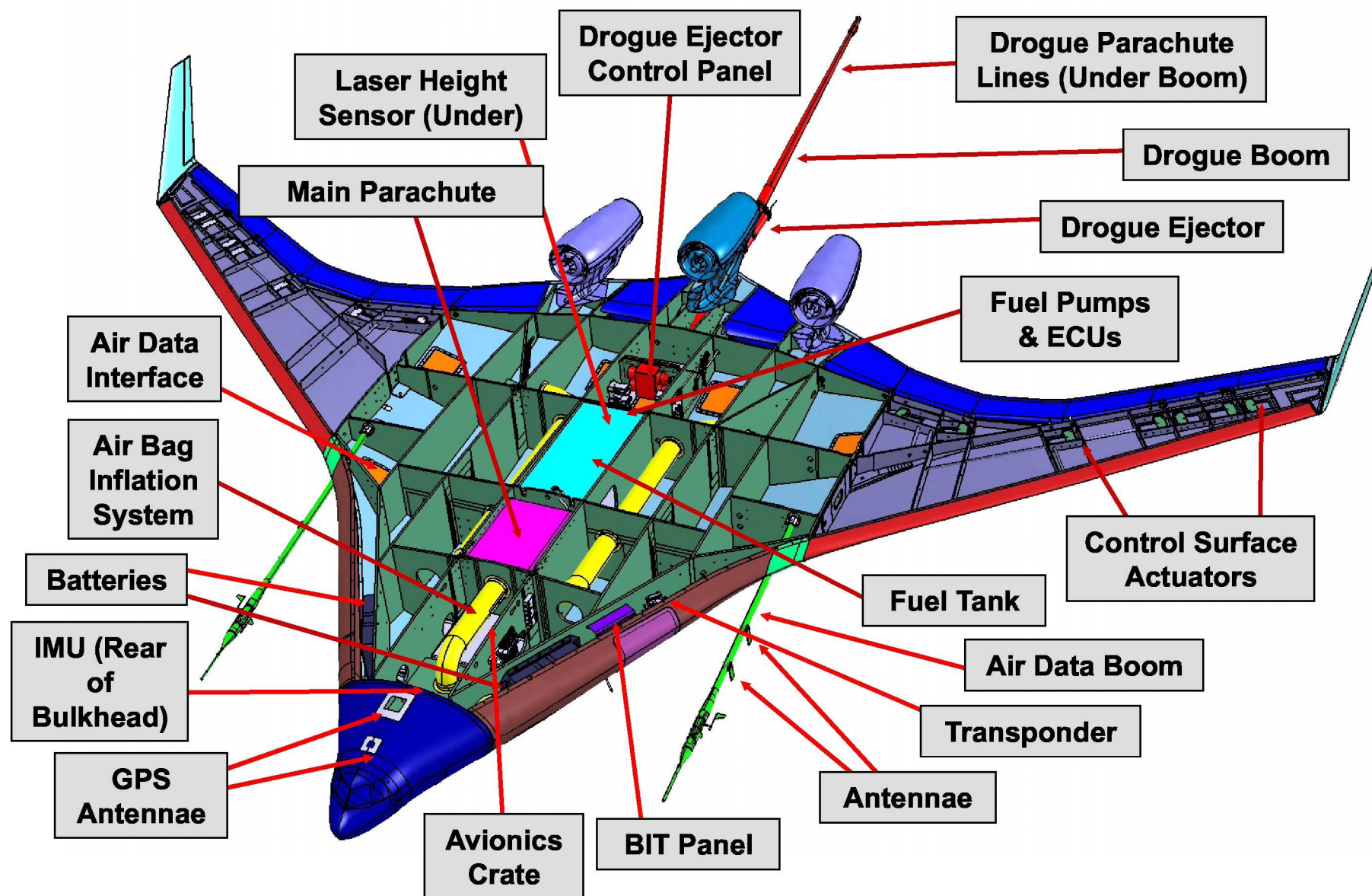
## X-48B Configuration – Top View





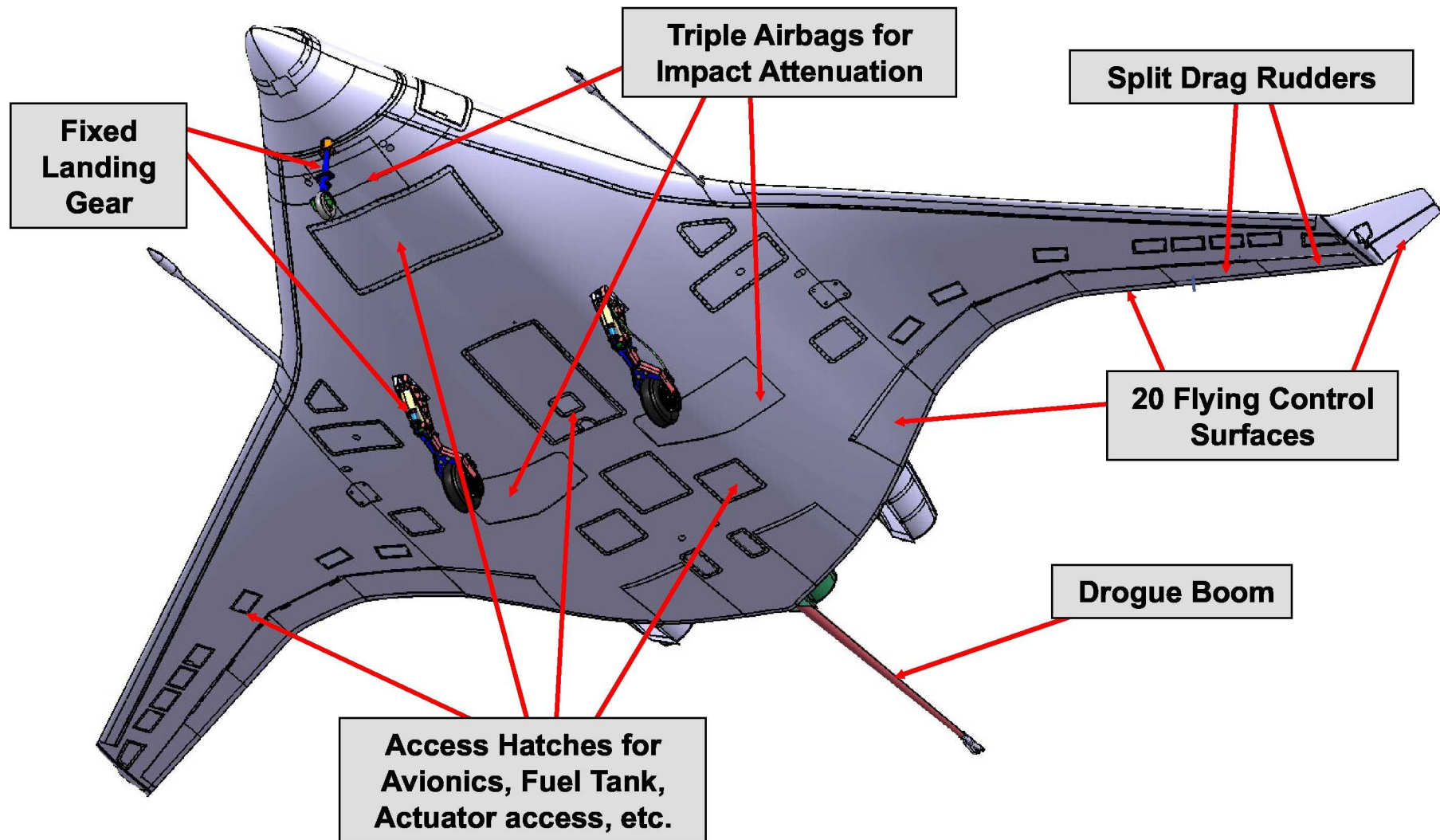


## X-48B Configuration – Internal View





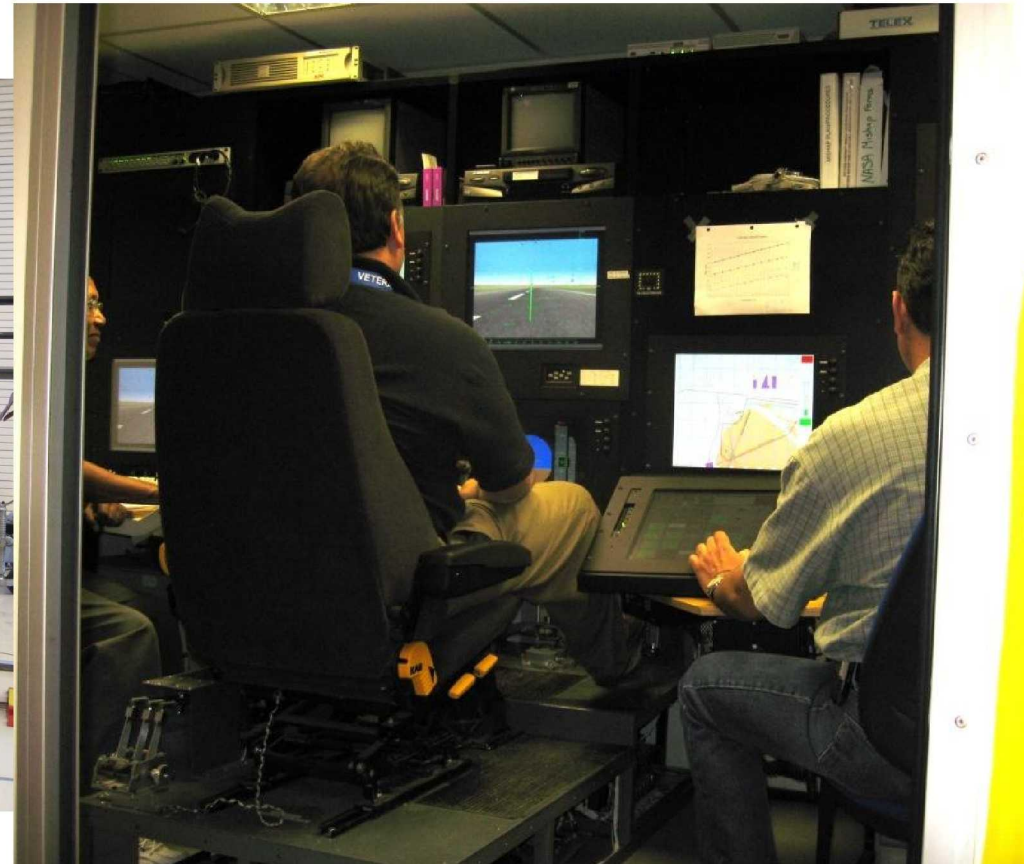
## ***X-48B Configuration – Underside View***







## Ground Control Station – Trailer







## ***X-48B Flight Research Summary - I***



- **Twenty Flights completed in Blocks 1 & 2 (Basic Envelope Expansion)**
  - 11 Flights w/ Slats Extended
    - Slats result in lower speeds and higher lift
  - 9 Flights w/ Slats Retracted
    - New Flight Control Laws / “1<sup>st</sup> Flight”
    - Envelope Expansion to Max Speed
- **Fourteen Flights completed in Block 3 (Initial High-Alpha Envelope Expansion)**
  - All 14 Flights w/ Slats Extended
  - Forward and Mid CG Locations





## ***X-48B Flight Research Summary - II***



- **Twenty-two Flights completed in Block 4 thus far (High-Alpha/Stall Assessments)**
  - Slats Extended & Retracted
  - Forward and Mid CG Locations
  - Relaxed Alpha Limiter
- **Highlights:**
  - Test Maneuvers
    - Real-Time Stability Margins
    - Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
    - Steady Heading Sideslips - Simulate Cross-wind landings
    - Low approaches and go-arounds for ground effects assessments
    - Lazy-8s and Wind-up Turns
    - AOA Build-up Maneuvers approaching  $C_{l,max}$
    - Flight Characteristics at Stall Boundaries



## *X-48B Initial Flight Research Results*



- Extremely maneuverable in roll
  - Stable in pitch at all CG locations, very stable in yaw
  - Aircraft very closely matches simulator for up/away flight (and landing)
  - Stall AOA matches wind tunnel measurements within 1 degree
  - Control system modeling generally matches actual flight behavior in the regions examined
- 
- Flight control design very robust – engine failures transparent to pilots
  - Overall, the aircraft flies extremely well





## ***X-48B What's Next for the Future***



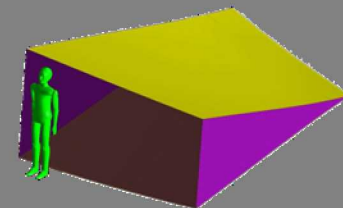
- Current plan to finish 100+ flights in CY2009
  - Follow-on Testing planned to continue thru FY2010
- Complete Phase 4 :
  - Stalls / High Alpha / Engine Out Assessments
- Phase 5/6:
  - Departure Resistance - Limiter Assaults / High Beta
- Potential new Engine Design
  - More Efficient = More Duration
- Low Noise Modifications (X-48C)
- Prop-Fan Version Demonstrator (X-48D)?
- Single Control Surface Aerodynamic Effects Measurements
- Intelligent/Adaptive Flight Controls – Gust Alleviation
- Larger Demonstrator Aircraft ???



# *The Vision*



**BWB Elevon #1**





# *X-48B in Flight*







# ***X-48B Flight Summary***



## **Flight Test Highlights**

- 56 Flights June 20, 2007 - present
- 10,000 ft. MSL Max Altitude
- 82 kts. Max Speed
- 16 deg. Max Angle of Attack
- 60 deg. Bank Turns
- Doublet, triplets, frequency sweeps
- 30 hours flight time total
- 13 deg. Max Angle of Sideslip



# *Small UAS Flight Operations*

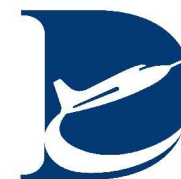




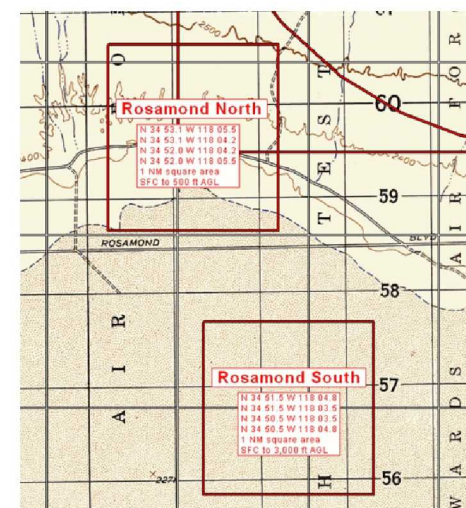
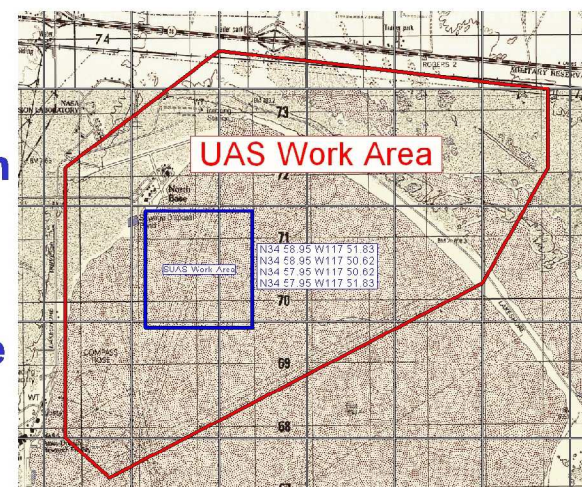


# Small UAS Test Area

## Fast & Efficient Test Capability



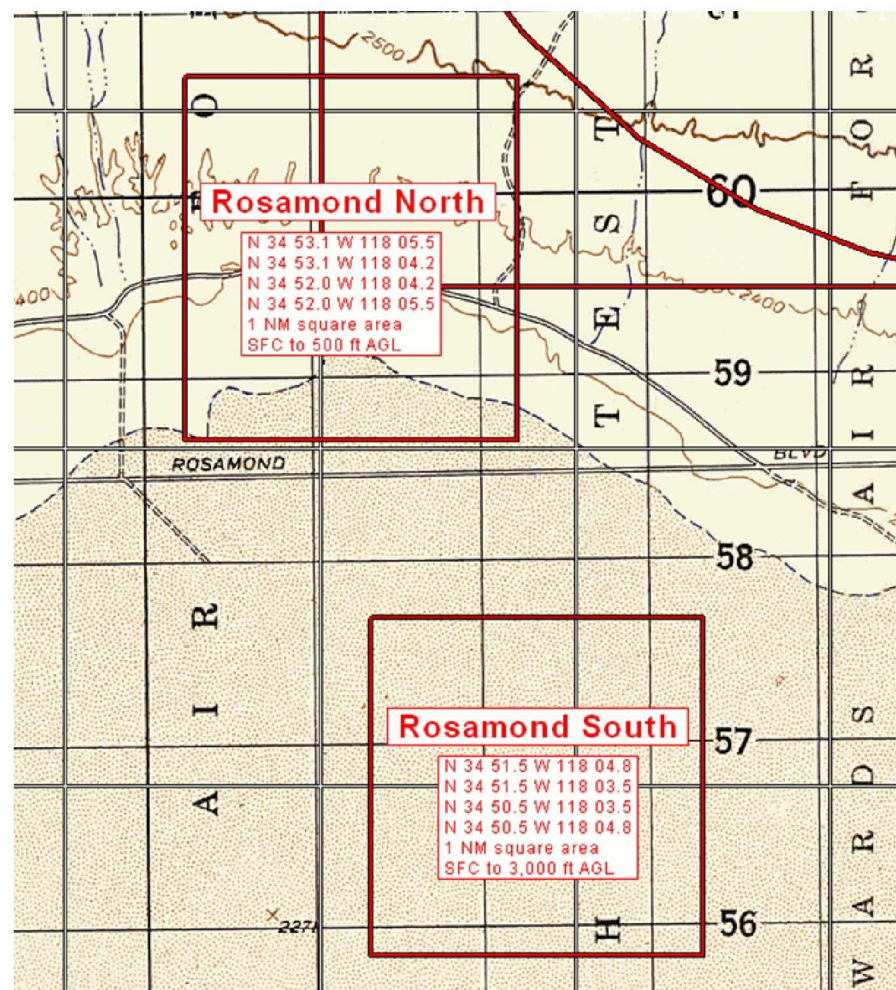
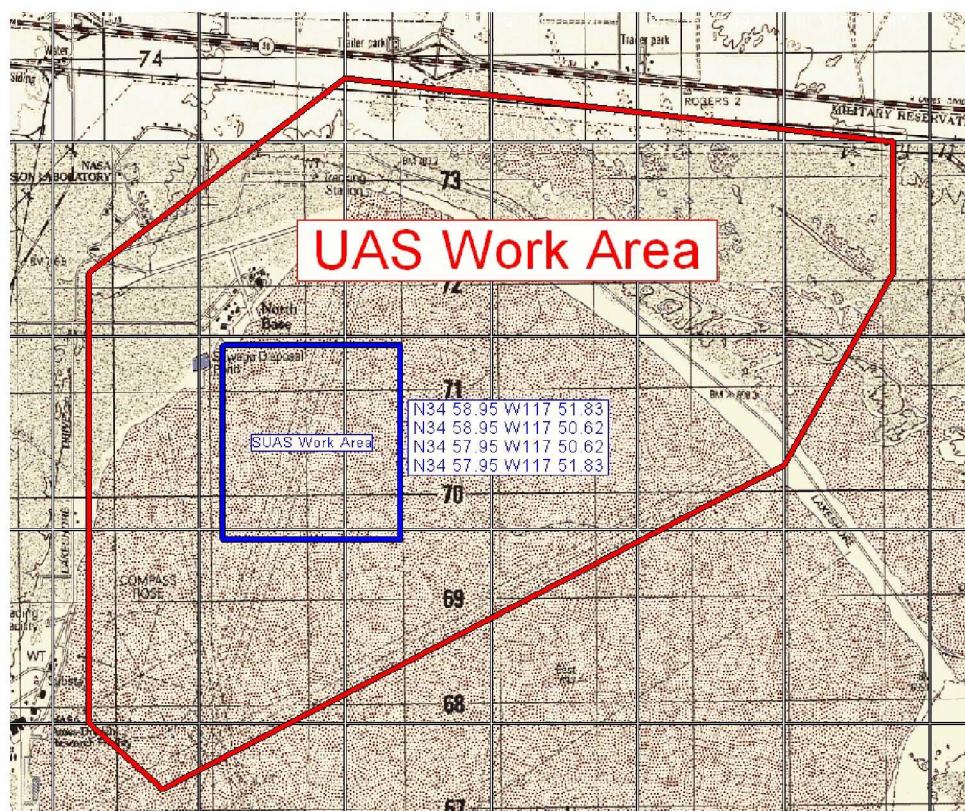
- Three test areas have been established within the restricted airspace of R2508 at Edwards AFB
  - NO FAA interface required for flight approval
- Rosamond North and South are 1 square nautical mile with operation ceilings of 500 and 3000 feet above ground level (AGL) respectively
- The larger SUAS work area located predominantly over the northern portion of Rogers dry lake is approximately 12 square miles with an operational ceiling of 8,000 feet AGL
- For operations where the vehicle performance is constrained to the approved areas a rapid approval process has been established.
- For operations where vehicle performance can not be constrained to within the approved areas or for operations that require additional air space, additional but still simplified review and flight approval process is possible







# Overview of Test Areas







# *Small UAS Operations*



- **To date DFRC has supported 5 different operations and is in the planning stage for more**
  - Most companies directly supporting warfighter
  - Some science, environmental, and development activities as well
- **Largely a service provided to customers who need access**
  - FAA restrictions (prohibition) of non-recreational UAS flight in the NAS
  - Restricted airspace over Edwards allows flight testing of systems
- **Pay-as-you-go system and approval process in place**
  - Minimal overhead
  - Minimal staffing



# *Agreements*



- **NASA Space Act Agreements**
  - Standard template developed allows for rapid approval by NASA
  - Agreement does not require surrender of intellectual property or transfer of assets to NASA





# ***Process***



- **Initiate contact**
  - **Complete questionnaire**
  - **Sign MOA**
  - **Send funding**
  - **Complete spectrum check**
  - **Schedule operation**
  - **Fly**
- 
- **This process can occur in as little as two weeks provided the questionnaire is filled out completely**



# Questions ?



Gary B. Cosentino  
NASA Dryden Flight Research Center  
Lead Flight Operations Engineer  
Science and UAV's  
[gary.b.cosentino@nasa.gov](mailto:gary.b.cosentino@nasa.gov)

